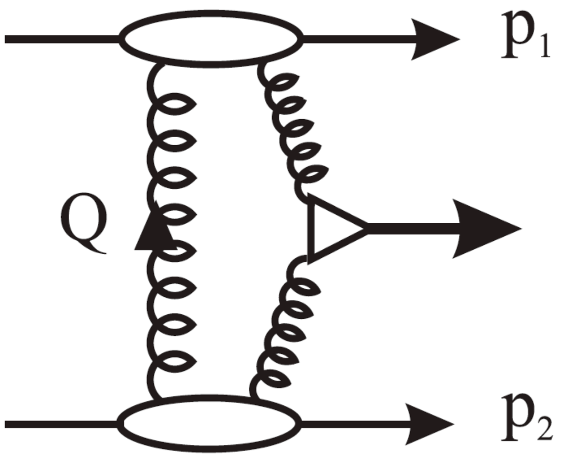
Forward Proton Tagging at the LHC



Motivation from KMR calculations (e.g. hep-ph 0111078)

- Selection rules mean that central system is (to a good approx) 0^{++}
- If you see a new particle produced exclusively with proton tags you know its quantum numbers
- Proton tagging may be the discovery channel in certain regions of the MSSM
- Tagging the protons means excellent mass resolution (~ GeV) irrespective of the decay products of the central system

1. Can we detect outgoing protons in interesting range of momentum loss ?
2. Can we use these protons to enhance the discovery potential of ATLAS ?

FP420 R&D Funding (ATLAS & CMS) :

"The panel believed that this offers a unique opportunity to extend the potential of the LHC and has the potential to give a high scientific return." - UK PPRP (PPARC)

R&D funding : £500k from UK (Silicon, detector stations, beam pipe + LHC optics and cryostat design), $100k from US (QUARTIC, Andrew Brandt/UTA), €100k Belgium (+Italy / Finland) (mechanics)

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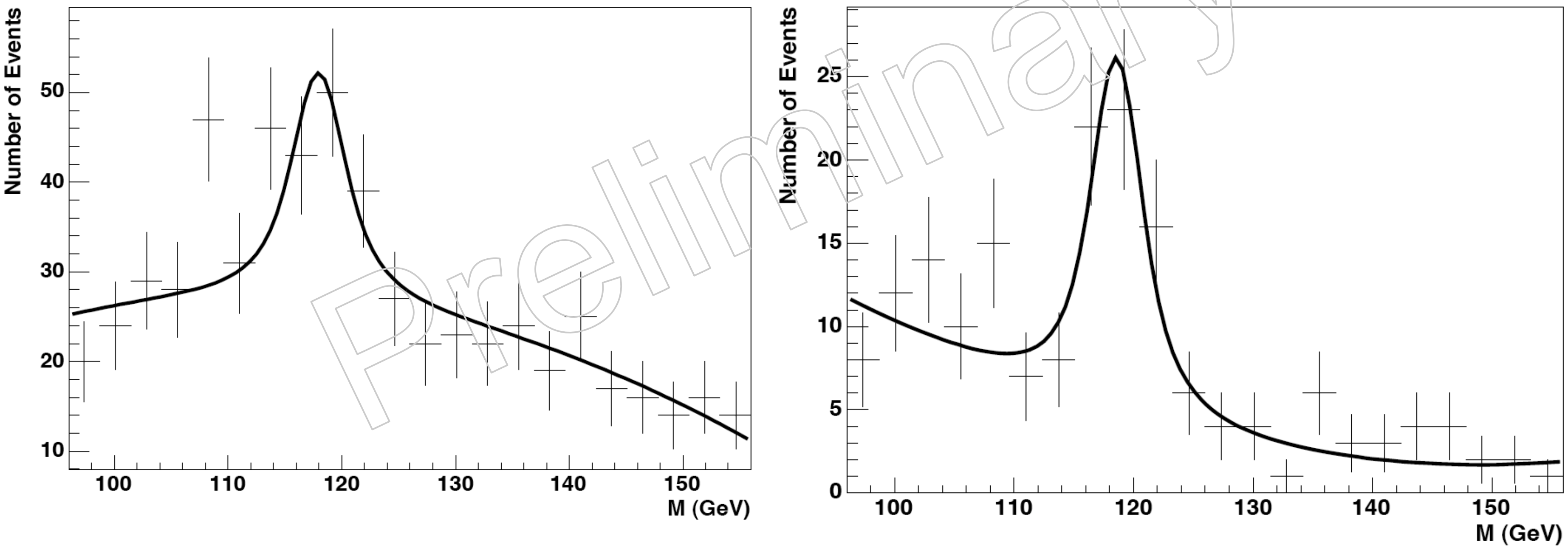
An example of what forward proton tagging could do

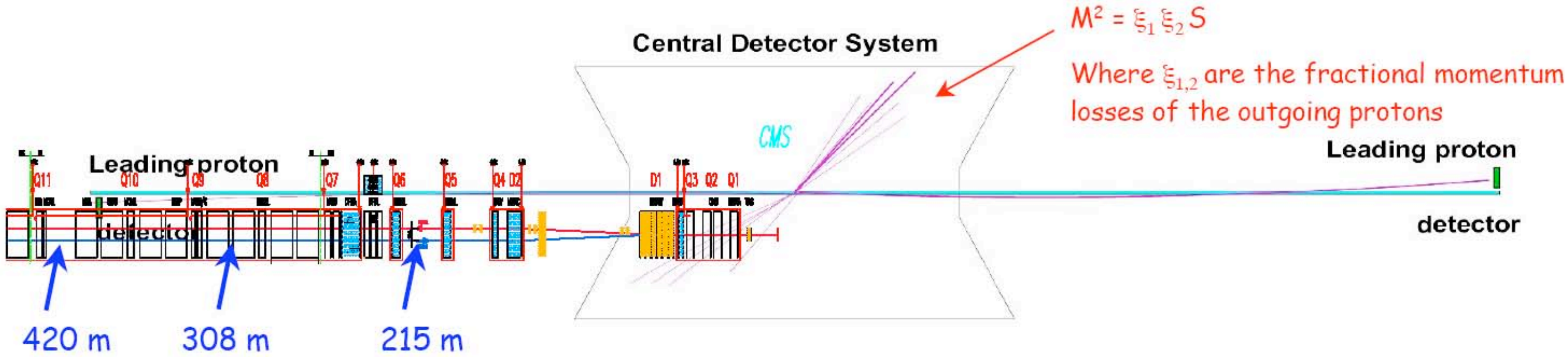
M_h^{max} MSSM scenario, b-jet channel, standard ATLAS L1 trigger thresholds:

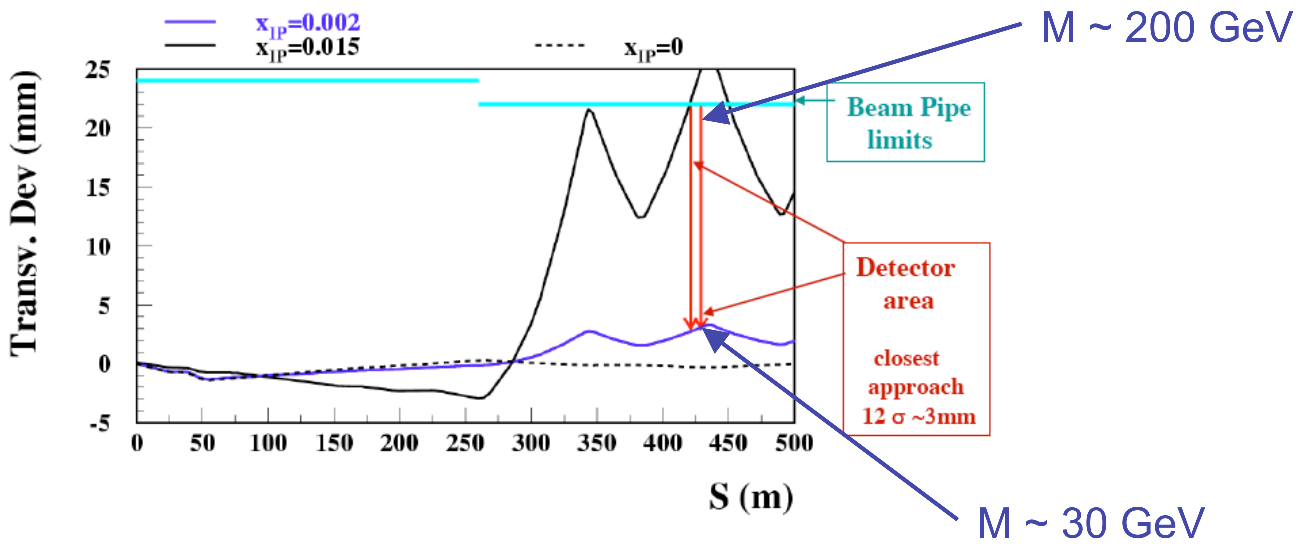
(m_A=120 GeV, tanβ = 40, 300fb^{-1} @ 10^{34} cm^{-2}s^{-1})



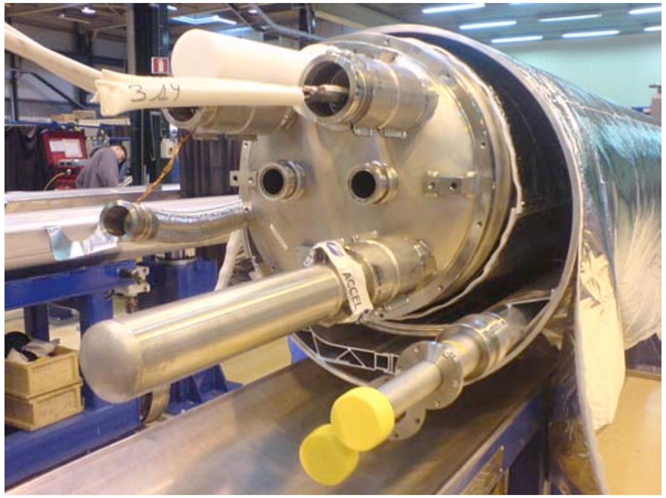
Schematic Outline

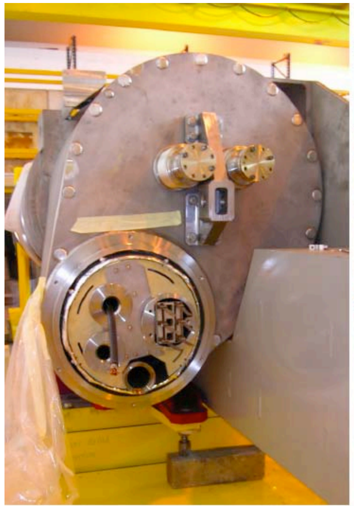
Spectrometer using LHC magnets to bend protons with small momentum loss out of the beam

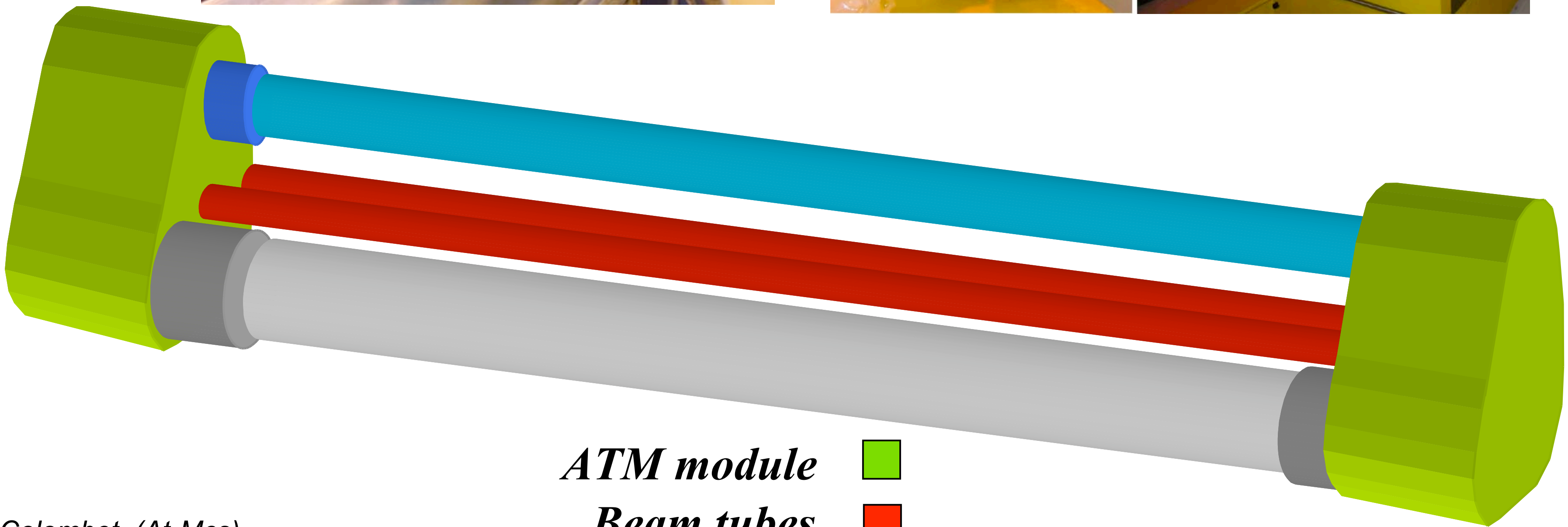




FP420 Connection Cryostat







ATM module

Beam tubes

Line X vacuum vessel

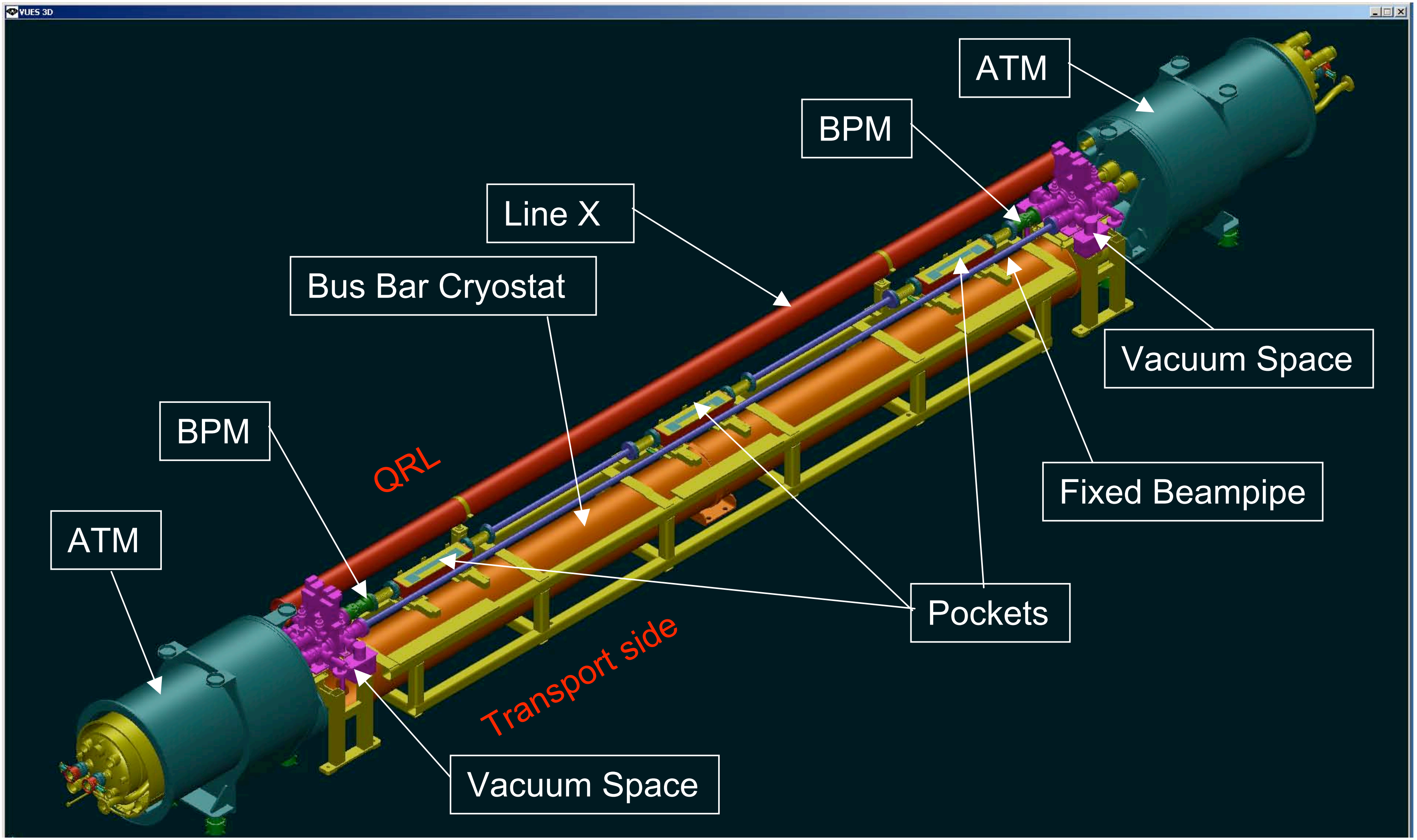
Connection Module

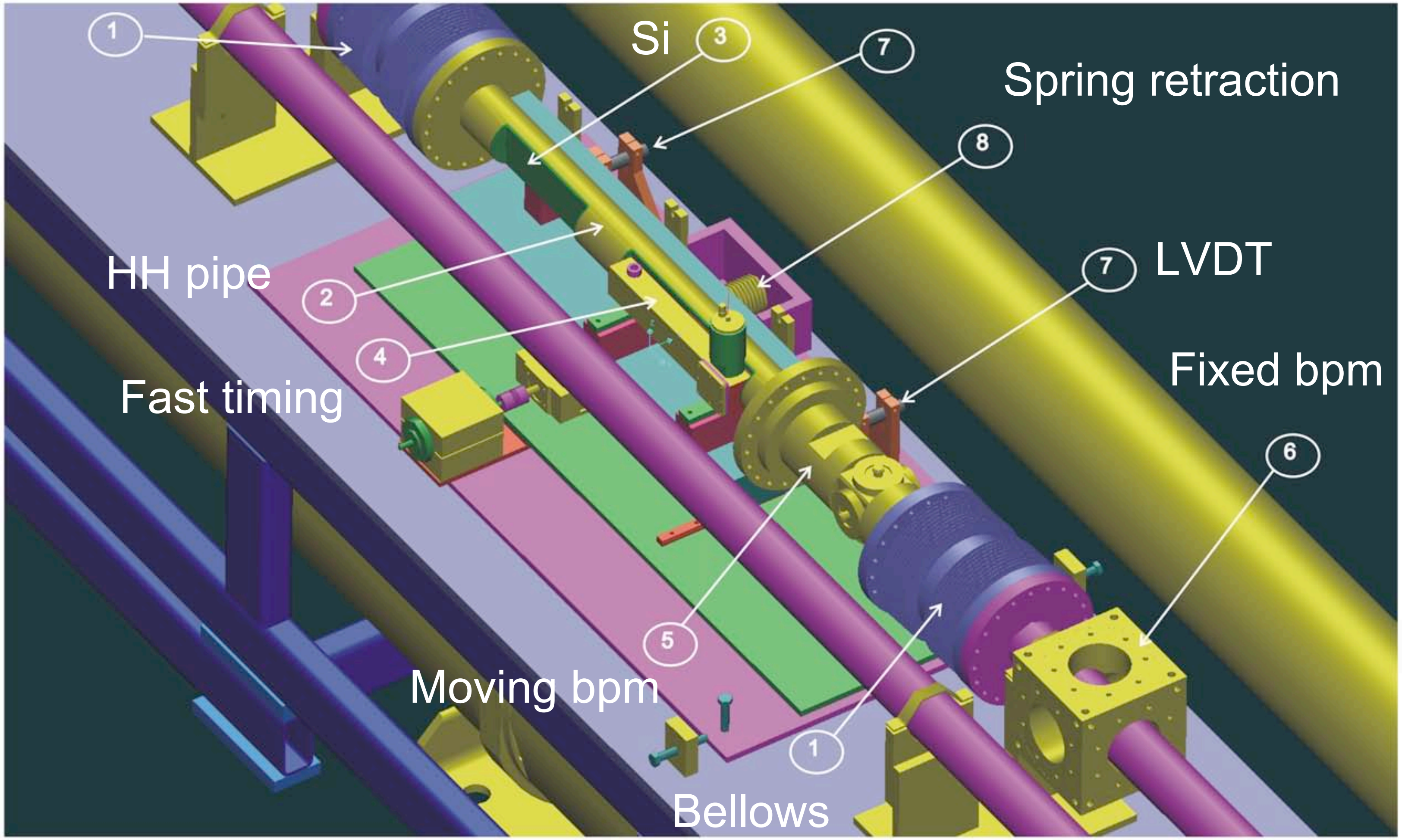
T. Colombet (At-Mcs)

T. Renaglia,

R. Folch

Integration of the moving beampipe and detectors




1
Si
3
7
Spring retraction
8
HH pipe
2
7
LVDT
4
Fixed bpm
Fast timing
6
5
Moving bpm
1
Bellows

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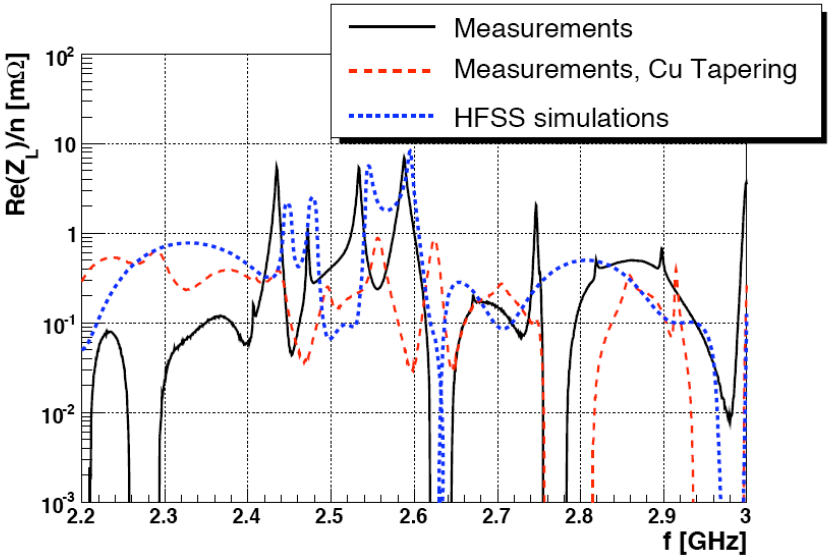
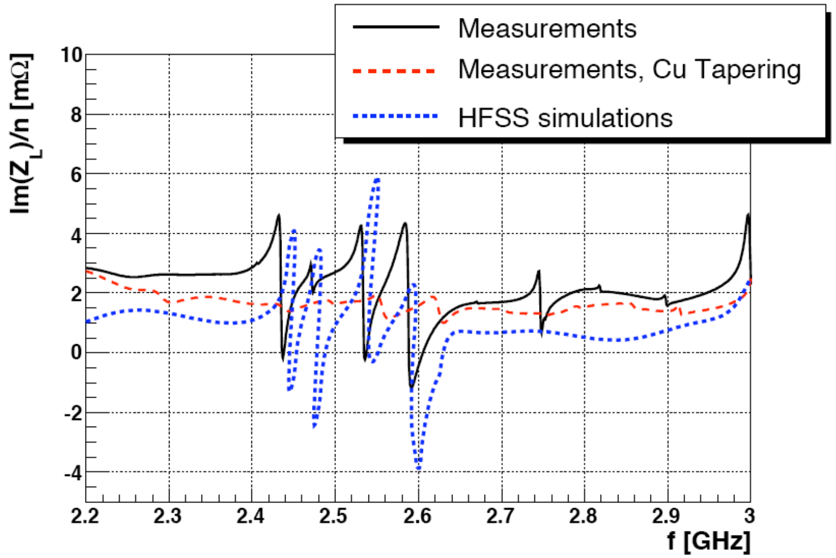
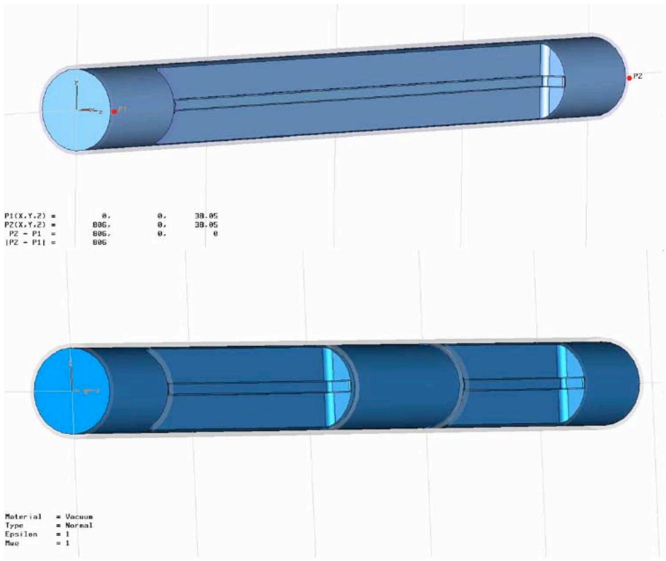
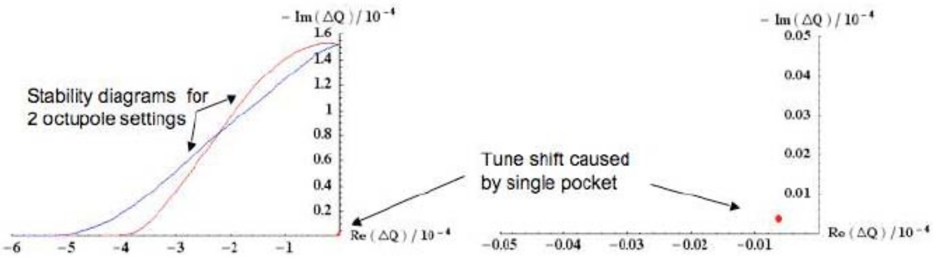
Impact of FP420 on LHC





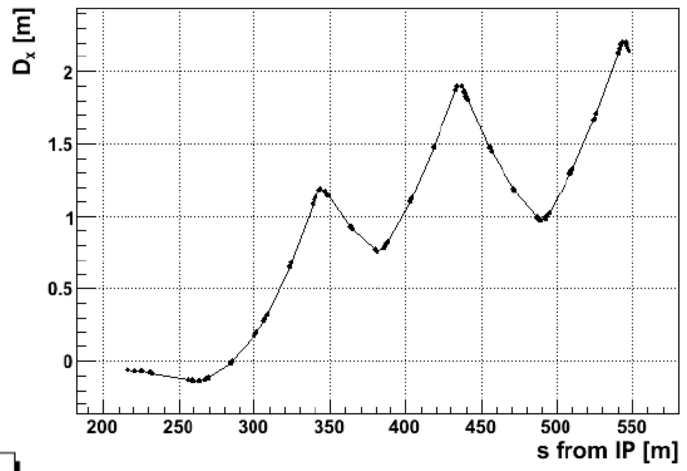


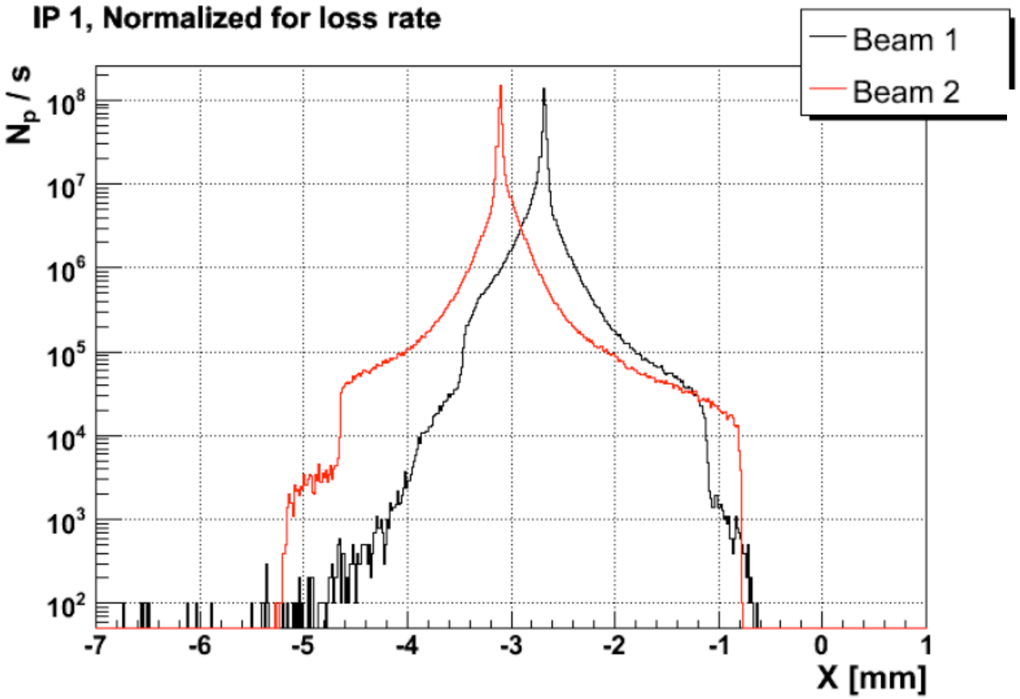
Ran simulations and measurements for 2 geometries - very small impact on LHC impedance budget

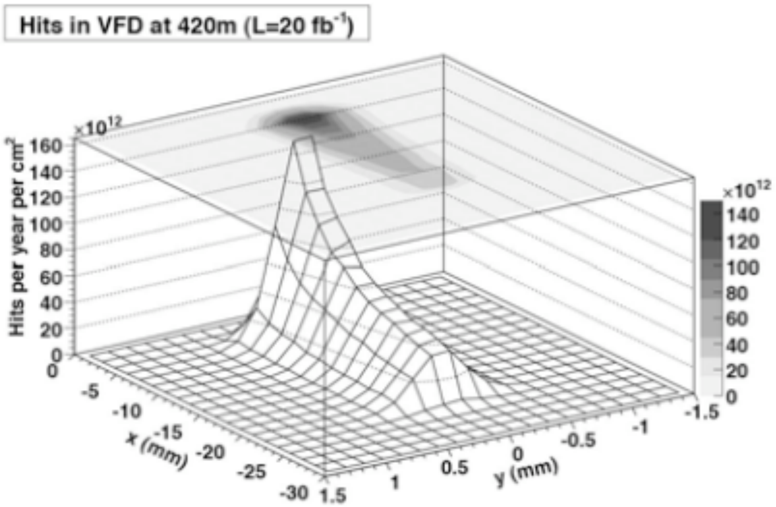


Backgrounds and distance of approach

System	n1 $[\sigma_{\beta x}]$	n2 $[\sigma_{\beta x}]$
Betatron Cleaning	6	7
Momentum Cleaning	15	18

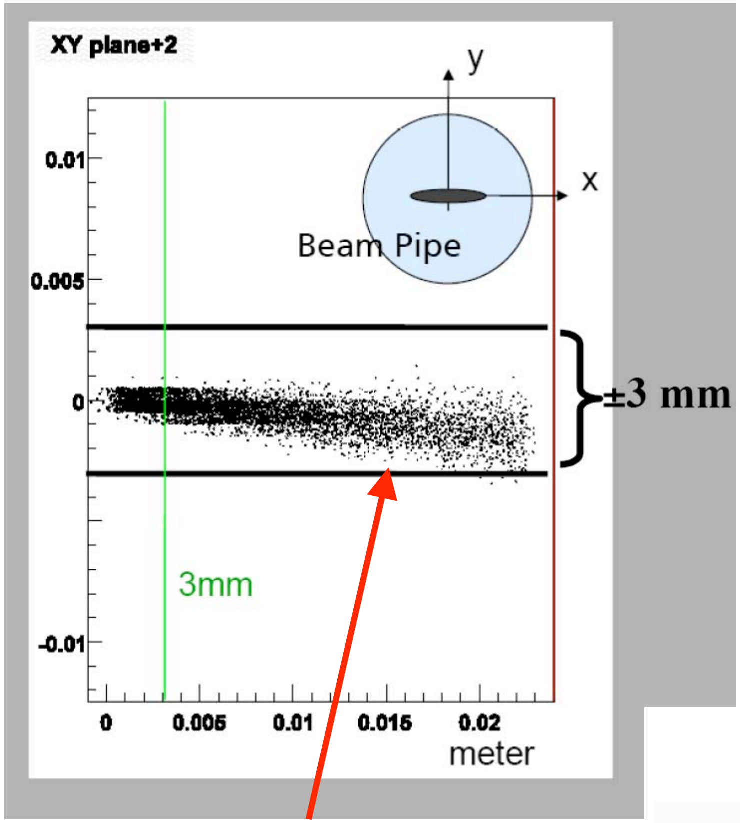




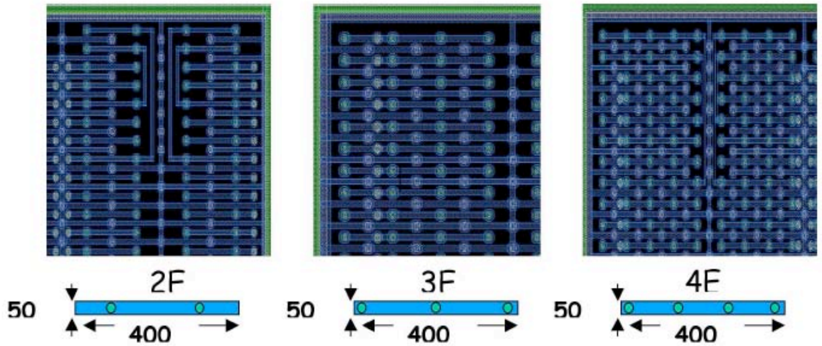


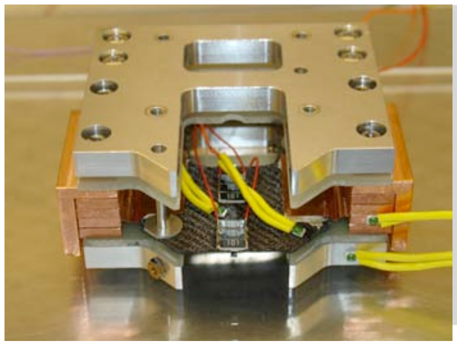
pp -> pX

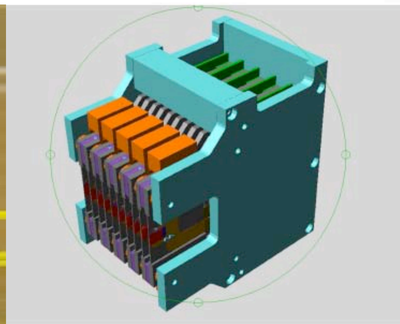
FP420 Silicon Detector Stations

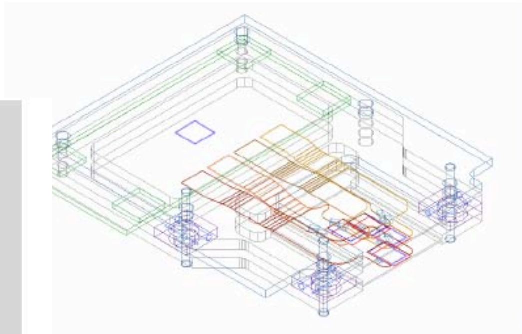


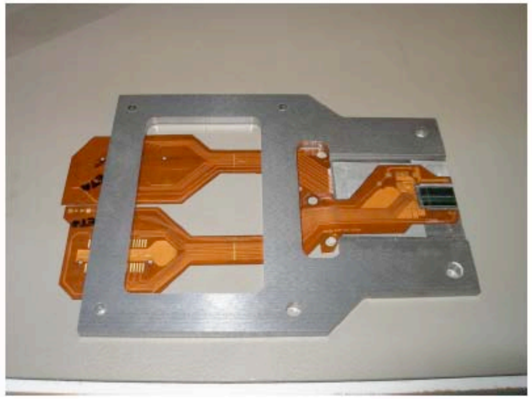
7.2 mm x 24mm (7.2 x 8 mm^2 sensors)



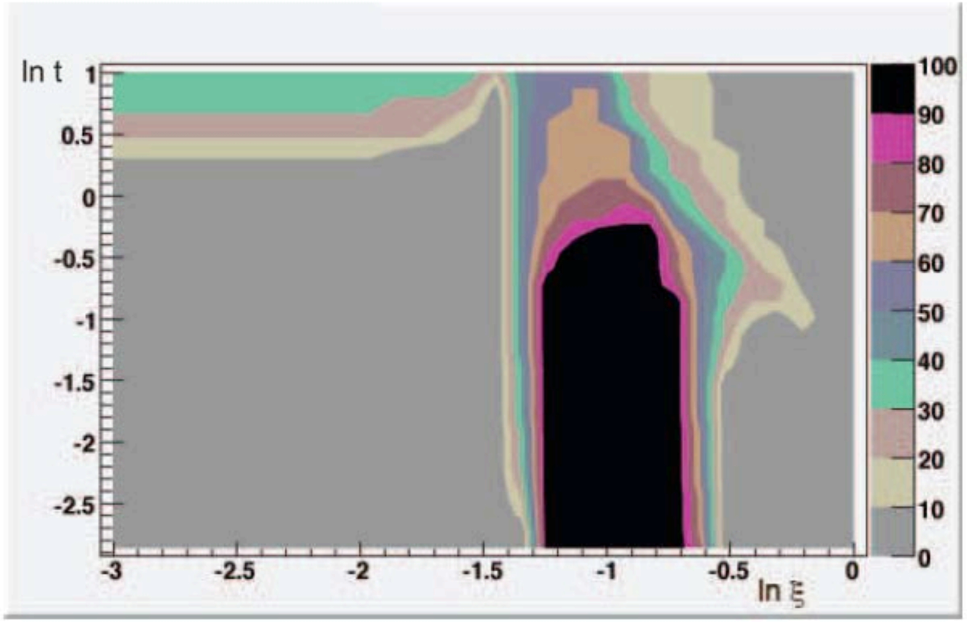


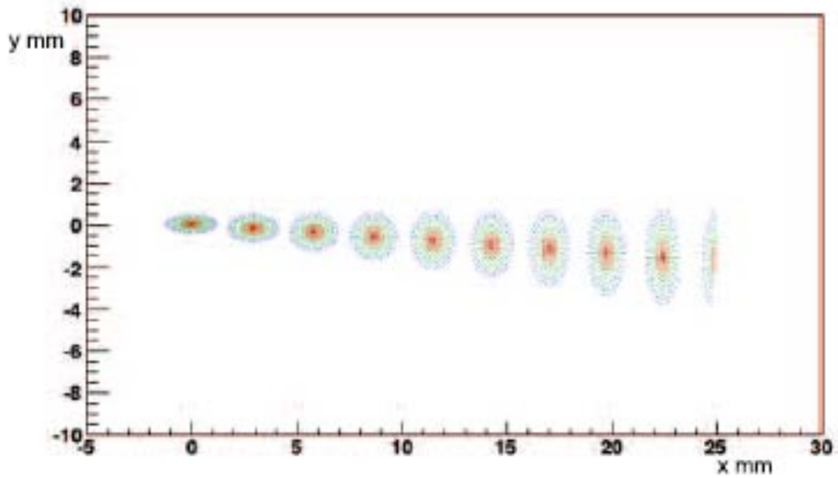






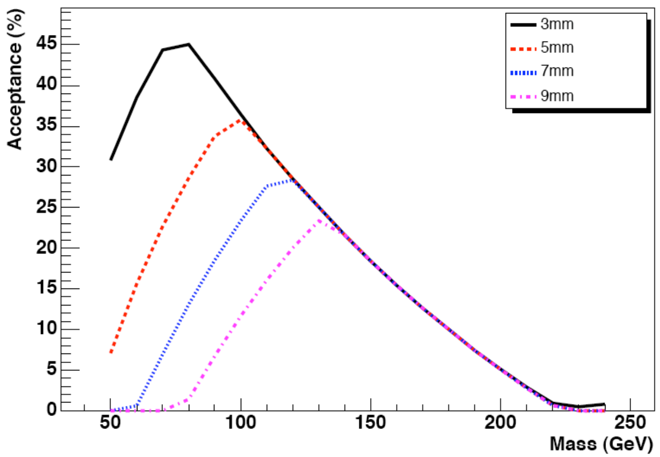
Acceptance and Resolution

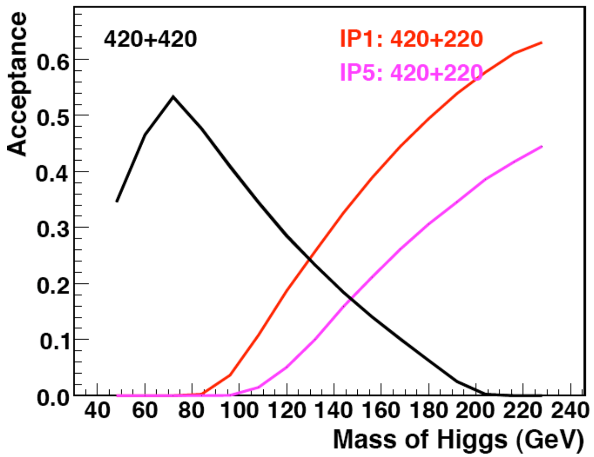


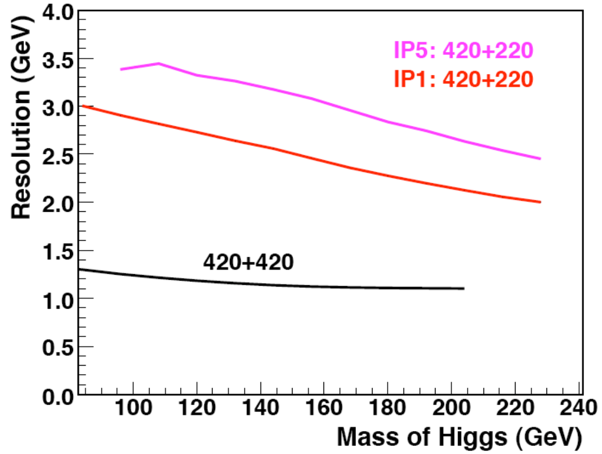


$\xi = 0$ (at x =0 mm, i.e. elastic scattering) to $\xi = 0.02$

t from 0 to $-0.2\ \mathrm{GeV}^2$







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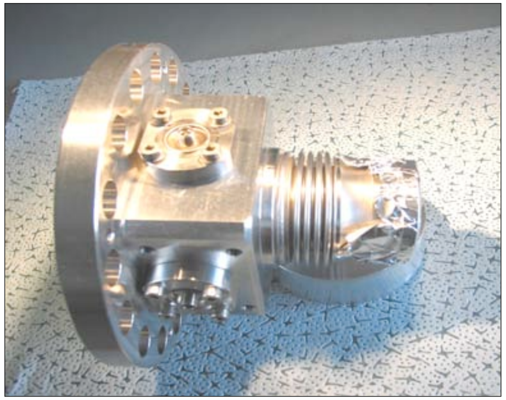
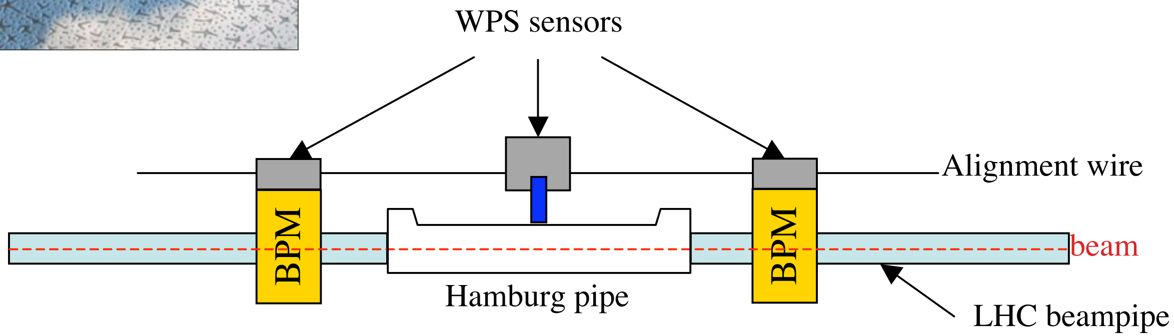
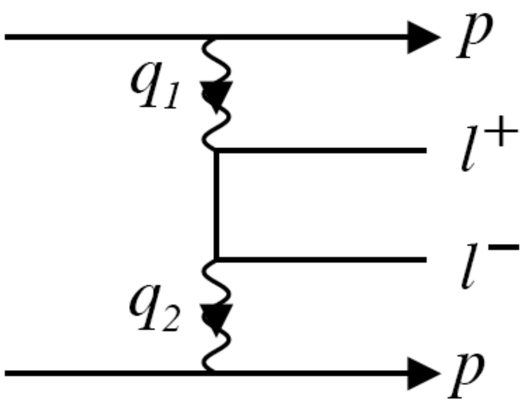
FP420 Alignment



CLIC BPMs + wire positioning system : aim for 10 microns relative to beam

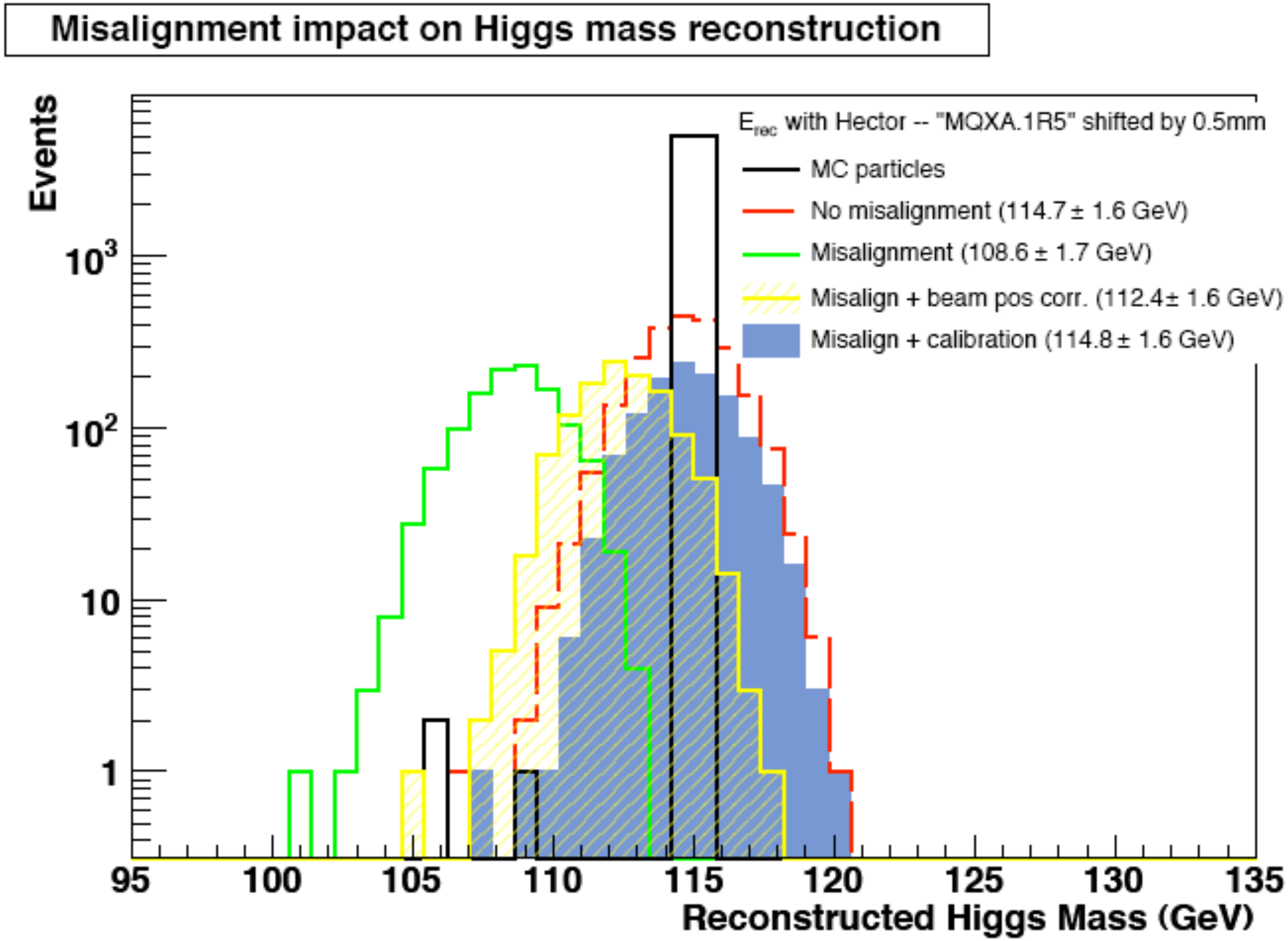




@ 10^{33} $cm^{-2}s^{-1}$ with standard ATLAS triggers, have ~ 30 di-muon events / fill in FP420 acceptance (σ ~ 7pb)

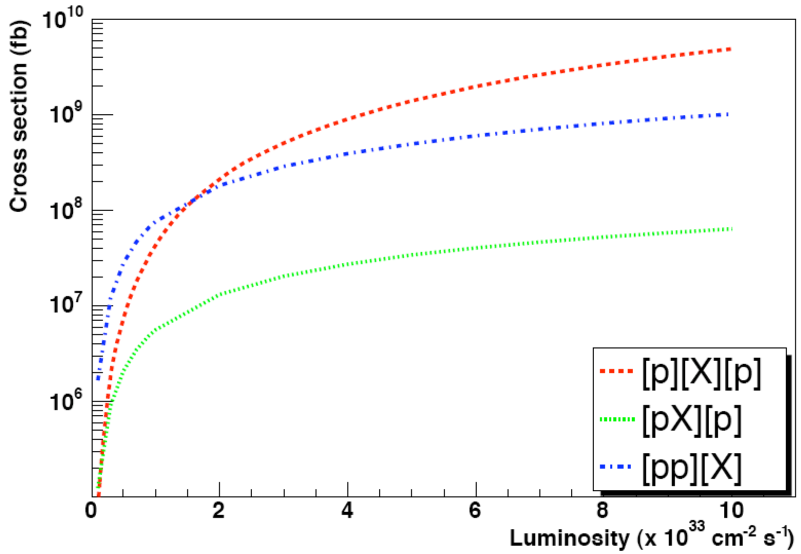
Thanks to Lars Soby, Rhodri Jones, Helene Mainaud-Durand, Andreas Herty and Robert Boudot

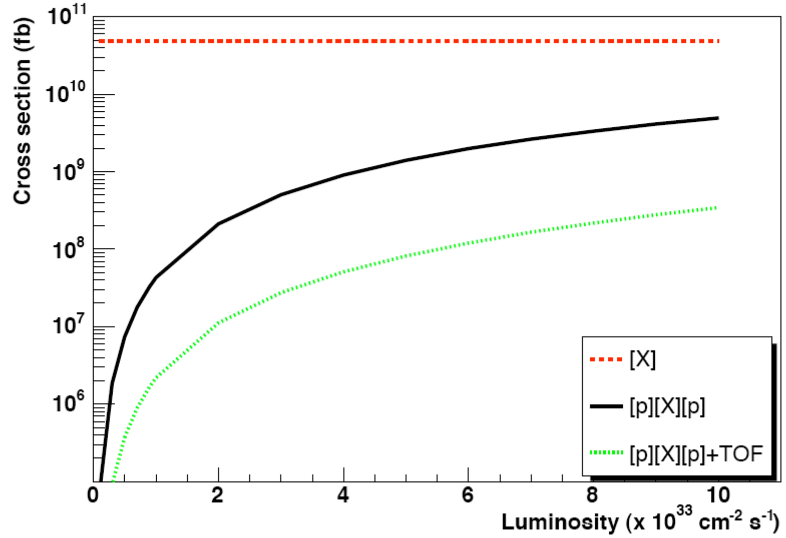
Mass and p_T reconstruction



FP420 Fast timing Detectors

Dijet cross sections, E_T > 40 GeV



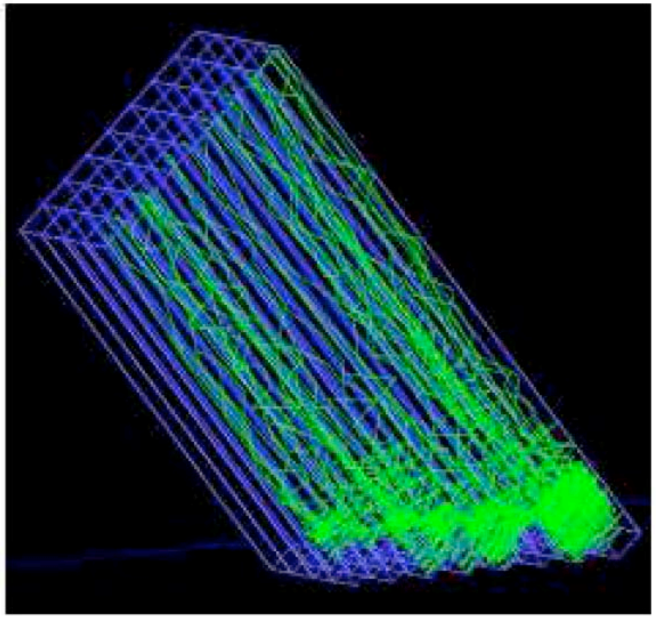


TOF 10ps (2.1mm)

- 1% of all events at LHC have diffractive proton track in FP420
- @ 2 x 10^{33} $cm^{-2}s^{-1}$, 7 interactions / bunch crossing
- -> 30% of FP420 events have an additional track
- Matching mass and rapidity of central system removes large fraction of these
- Of the remaining, 97.4% rejected by fast timing detectors with 10ps timing resolution (2.1 mm)

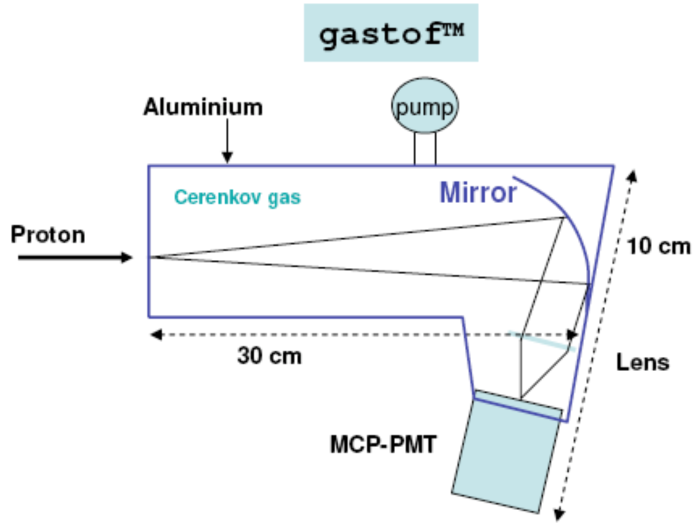
Fast timing detectors

Quartic (FNAL, Alberta, UTA)



More than 50% of the photons arrive within the first 5 ps.

GASTOF (Louvain)



all the photons arrive within ≈ 3 ps

Burle 85011-501 with 25 μm pores

Hamamatsu R3809U-50 with 6 μm pores

Test beam FNAL:

$$\delta t(G1) = 42 \text{ ps and } \delta t(G2) = 24 \text{ ps.}$$

$$\delta t(\text{QB4}) = 40 \text{ ps}$$

Burle 85011-501 with 10 μm pores

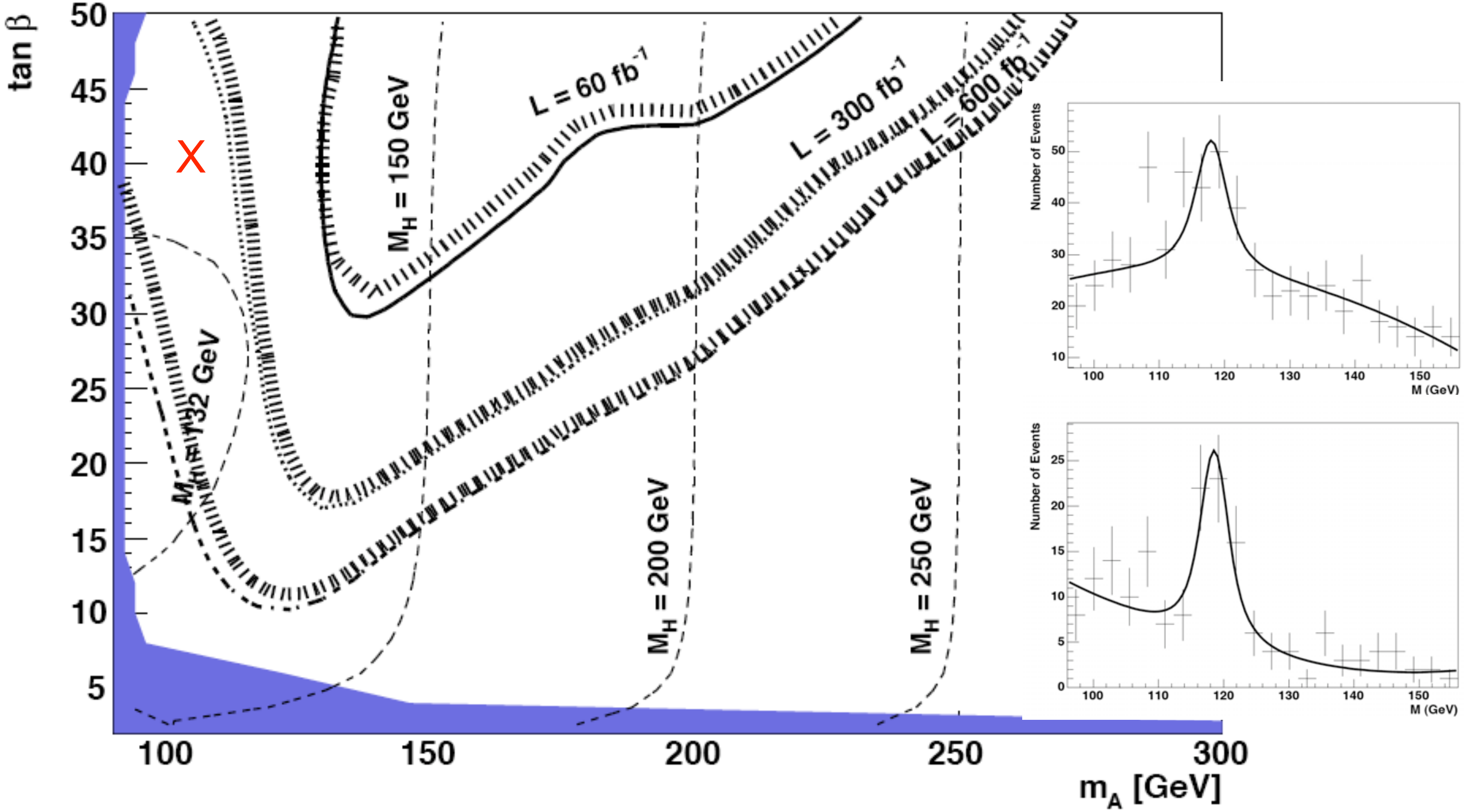
H-> b-jet Trigger

- 420m detectors can be integrated into L2, not L1
- Requiring two proton hits at L2 -> 2500 (250) reduction in di-jet E_T > 40 GeV rate @ 10^{33} (10^{34}) cm^{-2} s^{-1}
- 20Hz 420m output rate at L2 would be achieved by un-prescaled L1 @ 10^{33}, 5 kHz L1 @ 10^{34} cm^{-2} s^{-1}
- Also investigating low p_T muon trigger (~ 6 GeV) + 40 GeV jet

Simulated measurment @ 420m

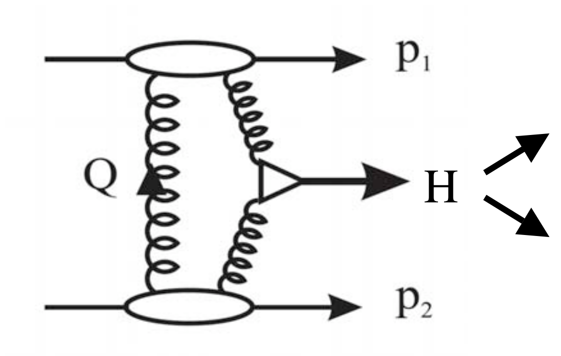
M_h^{max} benchmark scenario, H -> b-jets

Cox, Loebinger and Pilkington in prep.



S. Heinemeyer, V.A. Khoze, M.G. Ryskin, W.J. Stirling, M. Tasevsky and G. Weiglein, in preparation.

CEP production - many other interesting channels



0++ Selection rule

QCD Background ~ $\frac{m_b^2}{E_T^2}\,\frac{\alpha_S^2}{M_{b\bar{b}}^2 E_T^2}$

Higgs Quantum Numbers / mass resolution

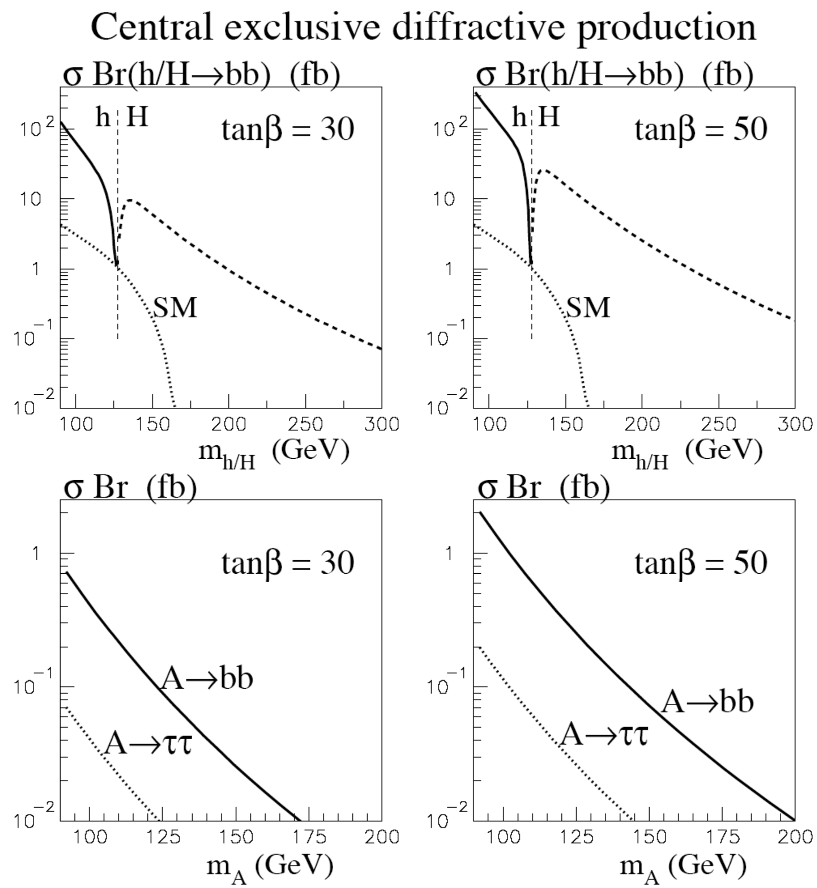
WW* : M_H = 120 GeV σ = 0.4 fb

M_H = 140 GeV σ = 1 fb

M_H = 200 GeV σ = 0.5 fb

M_H = 140 GeV : 5 (10) signal (1 (2) "gold platted" dl), very small backgrounds in 30 fb^{-1}

B.E. Cox. et al, Eur. Phys. J. C 45, 401-407 (2006)



M_A = 130 GeV, tan β = 50

M_h = 124 GeV : 71 signal in 30 fb^{-1}

M_H = 135 GeV : 124 signal in 30 fb^{-1}

M_A = 130 GeV : 1 signal in 30 fb^{-1}

A. B. Kaidalov. et al, Eur.Phys.J. C33 (2004) 261-271

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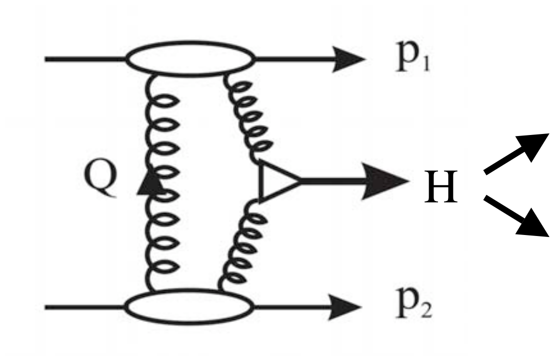
CEP production - many other interesting channels



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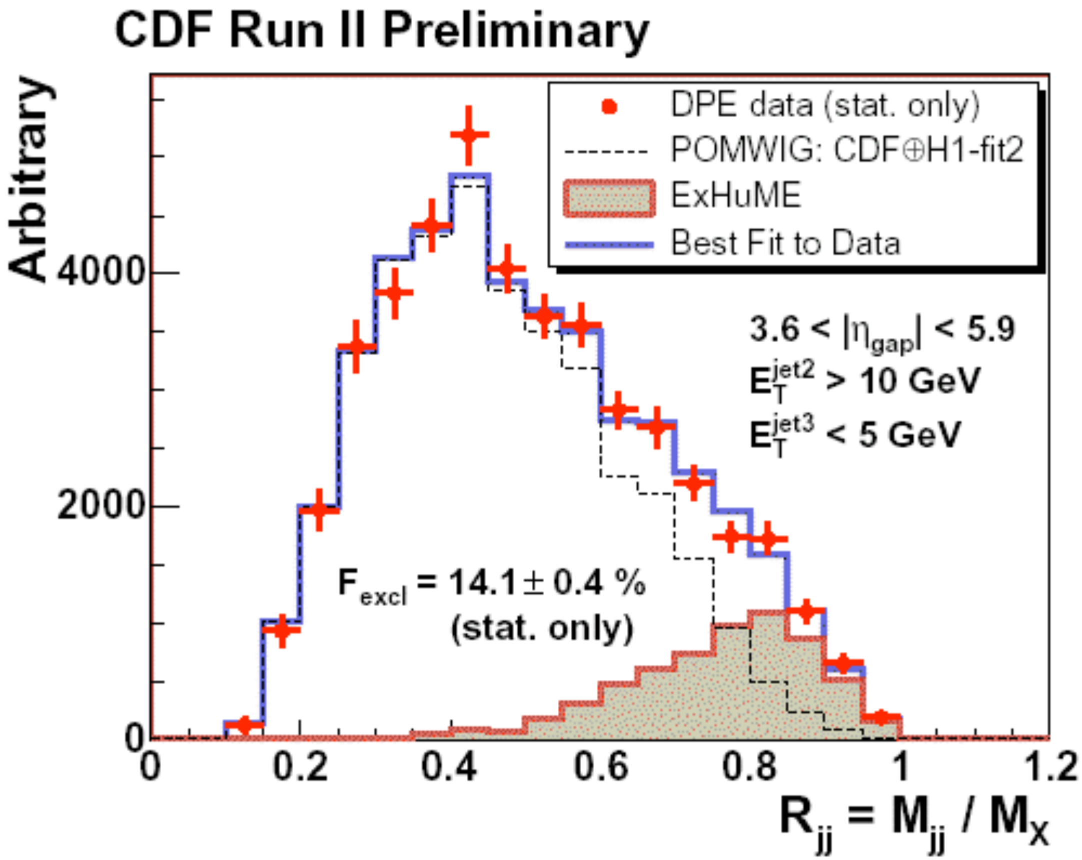
Higgs Quantum Numbers / mass resoluti



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Probing CP violation in the Higgs Sector

Azimuthal asymmetry in tagged protons provides direct evidence for CP violation in Higgs sector

$$A = \frac{\sigma(\varphi < \pi) - \sigma(\varphi > \pi)}{\sigma(\varphi < \pi) + \sigma(\varphi > \pi)}$$

$M(H_1)$ GeV	cuts	30	40	50
$\sigma(H_1)\mathrm{Br}(\tau\tau)$	a, b	1.9	0.6	0.3
$\sigma^{\mathrm{QED}}(\tau\tau)$	a, b	0.2	0.1	0.04
$A_{\tau\tau}$	b	0.2	0.1	0.05

(b) $p_i^{\perp} > 300$ MeV for the forward outgoing protons

'CPX' scenario
σ in fb

$$\mathcal{M} = g_S \cdot (e_1^{\perp} \cdot e_2^{\perp}) - g_P \cdot \varepsilon^{\mu\nu\alpha\beta} e_{1\mu} e_{2\nu} p_{1\alpha} p_{2\beta} / (p_1 \cdot p_2)$$

CP even

CP odd active at non-zero t

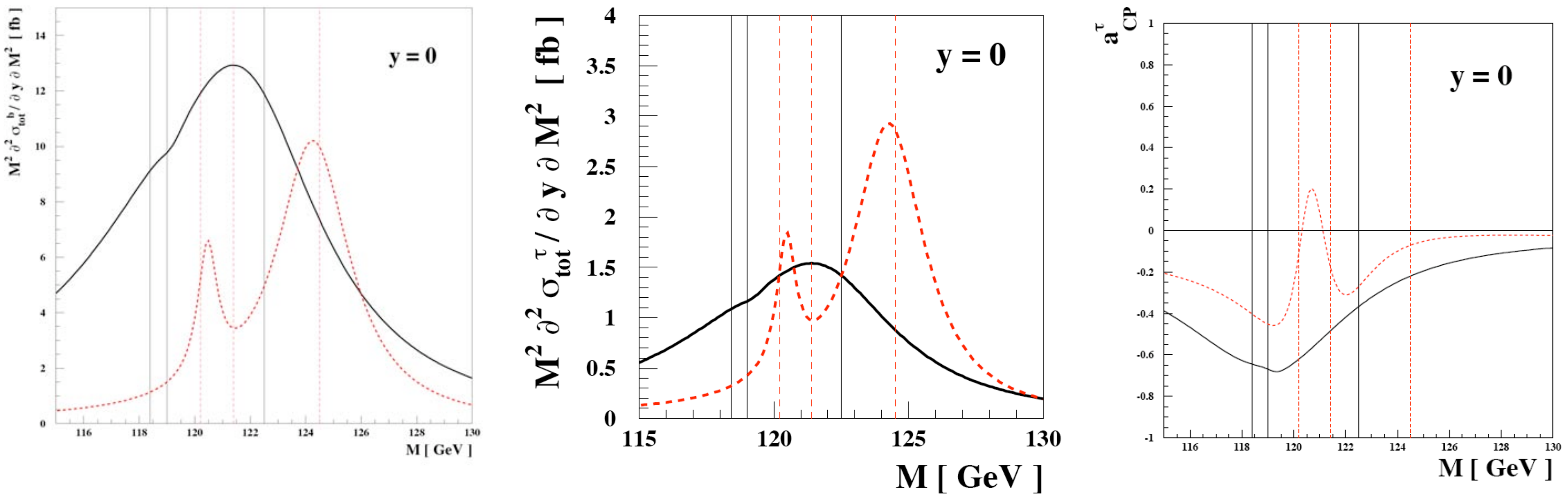
Ongoing work - are there regions of MSSM parameter space where there are large CP violating couplings AND enhanced gluon couplings?

B.C., Forshaw, Lee, Monk and Pilaftsis Phys. Rev. D. 68 (2003) 075004

Khoze, Martin and Ryskin Eur. Phys. J. C 24 (2004) 327

CP violation in the Higgs Sector

bb decay | ττ decay | ττ decay



This example shows that exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production. In particular, we have shown that exclusive double diffraction constitutes an efficient CP and lineshape analyzer of the resonant Higgs-boson dynamics in multi-Higgs models. In the specific case of CP-violating MSSM Higgs physics discussed here, which is potentially of great importance for electroweak baryogenesis, diffractive production may be the most promising probe at the LHC.

J. Ellis et al hep-ph/0502251

Forward Physics upgardes at the LHC

- FP420 is currently an R&D collaboration between ATLAS, CMS and non-affiliated groups.
- In addition, there is a strong, complementary program to upgrade the 220m region which adds value to 420m program
- Aim is to submit proposal to ATLAS for a sub-detector upgrade this year for 420m and 220m upgrades
- If accepted by ATLAS and / or CMS, this would lead to TDR from experiment to LHCC late 2007 / early 2008
- The FP420 design phase is fully funded, and will be completed in summer 2007
- If funding is secured, cryostats (built by TS-MME) and baseline detectors could be ready for installation in Autumn 2008.
- However, more likely goal is autumn 2010
- 220m and 420m tagging detectors have the potential to add significantly to the discovery reach of ATLAS and CMS for modest cost, particularly in certain regions of MSSM parameter space
- There is a rich QCD and electroweak physics program in parallel with discovery physics

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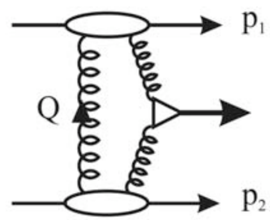
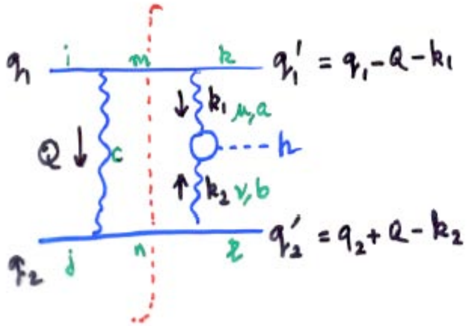
The KMR Calculation of the Exclusive Process



$qq \to q + H + q$



q -> Proton

$$\frac{d\sigma}{dy_H} \simeq \frac{1}{256\pi b^2}\,\frac{\alpha_s^2 G_F \sqrt{2}}{9}\left[\int \frac{d^2Q_\perp}{Q_\perp^4}\, f(x_1, Q_\perp^2)\, f(x_2, Q_\perp^2)\right]^2$$

$$f(x_i, Q_\perp^2) = \frac{\partial G(x_i, Q_\perp^2)}{\partial Q_\perp^2} \qquad (x_i = \alpha_i)$$

Dominant uncertainty: KMR estimate factor of 2-3.

assuming $f \sim (Q^2)^\gamma$

$$Q \sim \frac{M_H}{2}\exp\left(-\frac{2\pi}{N_c\alpha_s}\,\frac{\left[\frac{n}{2}-1-2\gamma\right]}{2}\right)$$

$\alpha_s = 0.2,\; M_H = 100$ GeV, $n = 4$, $\gamma = 0.2$

→ 2 GeV

Power of Q_T, 6 for pseudo-scalar

Divergent: controlled by Sudakov

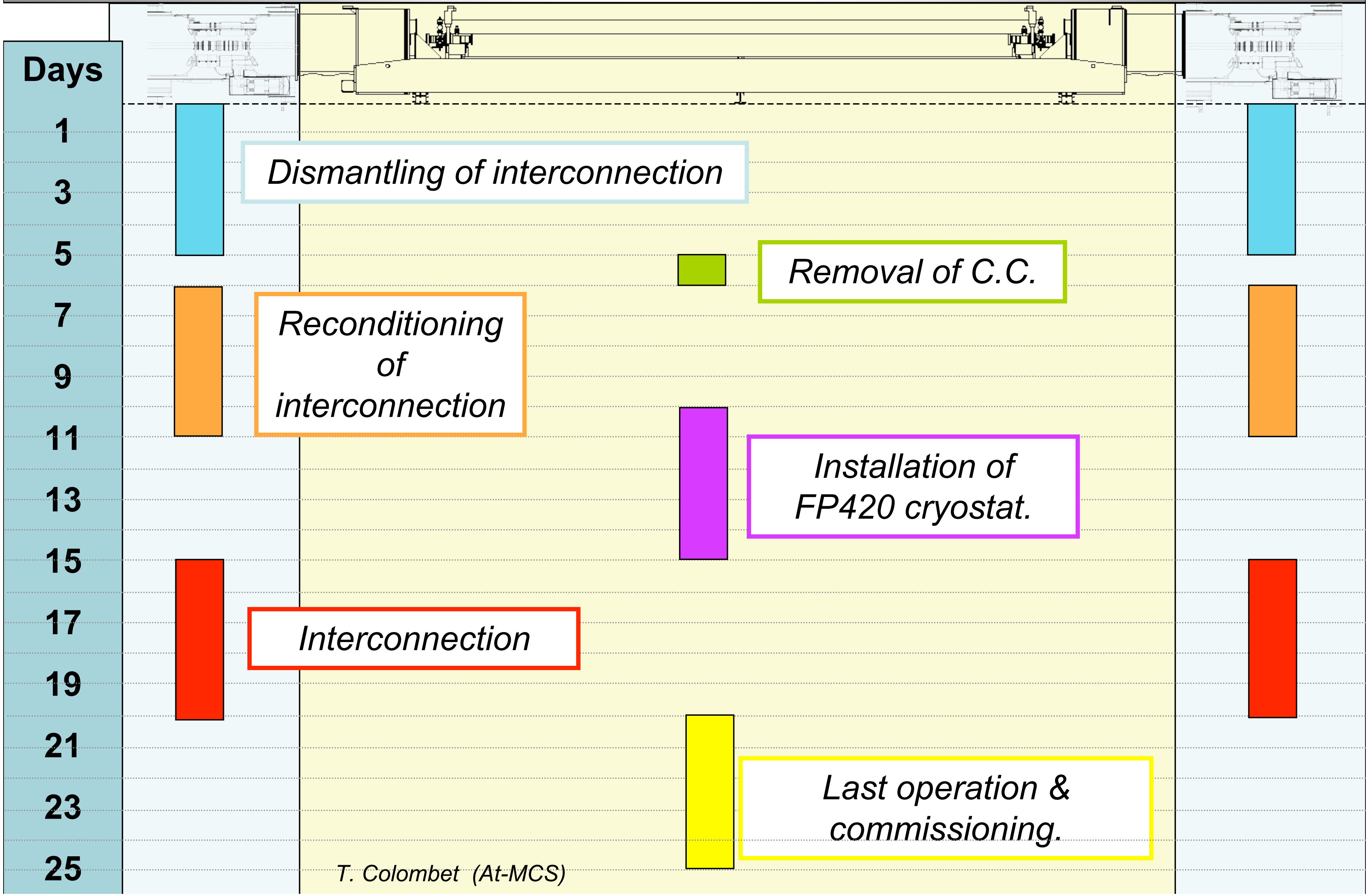
As $Q_T \to 0$ so the screening gluon fails to screen and $P_T \approx 0$ emission is allowed. Hence e^{-S} vanishes faster than any power of Q_T.

exponentiating generates a factor in amplitude of

$$\exp(-S) = \exp\left(-\frac{C_A}{\pi}\int_{Q_T^2}^{M_H^2/4} \alpha_s \frac{dp_T^2}{p_T^2}\int_{p_T}^{M_H/2}\frac{dE}{E}\right) \longleftarrow \text{double logs}$$

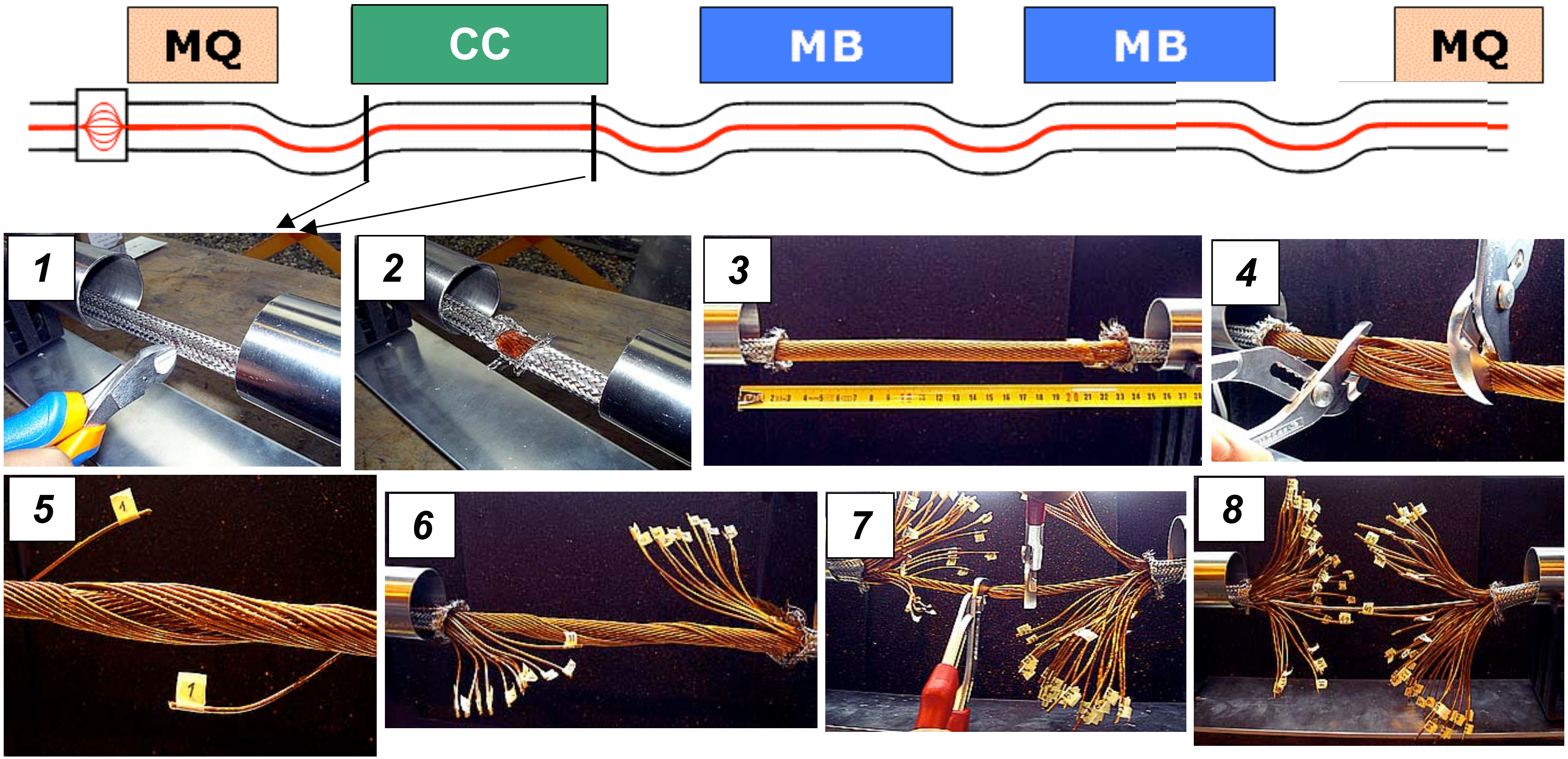
Jeff Forshaw, this workshop

Preliminary planning of interconnection:



Dismantling of interconnections :

Line N dismantling :



T. Colombet (At-MCS)

2 peoples	12 hours + previous (4 hours) = 2 days

Generator		ξ range			
		0.002 - 0.02	0.02 - 0.05	0.02 - 0.1	0.02 - 0.2
Durham	(SD)	0.0112	0.0040	0.0070	0.0098
PYTHIA	(SD)	0.0104	0.0045	0.0081	0.0112
	(ND)	0.0002	0.0016	0.0043	0.0124
PHOJET	(SD)	0.0069	0.0031	0.0055	0.0081
	(SD + DPE)	0.0097	0.0045	0.0081	0.0118
	(ND)	0.0018	0.0025	0.0059	0.0192

Table 1: The fraction of events at the LHC that produce a forward proton on one side of the interaction point in a specific kinematic range. The PYTHIA and PHOJET event generators are compared to the single diffractive cross section given in equation 5. SD labels the outgoing proton from single diffractive scatters and ND labels the protons produced from non-diffractive scatters. DPE labels double pomeron exchange events.

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Installation Schedule

	Normal Days
Warmup from 1.9K to 4.5 K	1
Warmup from 4.5K to 300 K	15
Venting	2
Dismantling interconnection	10
Removal of the connection cryostat	2
Installation of the FP420 cryostat	5
Realization of the interconnections	15
Leak test and electrical test	4
Closing of the vacuum vessel	1
Evacuation/repump	10
Leak test	2
Pressure test	4
Cooldown from 300 K to 4.5 K	15
Cooldown from 4.5K to 1.9 K	3
Total [days]	89

Table 4: The estimated time in days required to install one NCC